Chronic toxicity to fish: Overview of potential population impairment in the San Francisco estuary and its catchment

Prepared by the PWT Contaminants Group

Introduction

Many fish populations in the San Francisco Bay-Delta system are in serious decline, including winter-run Chinook salmon *(Onchorhynchus tshawytscha)*, the striped bass *(Morone saxatilis)*, the Sacramento Splittail *(Pogonichthys macrolepidotus)*, the Longfin Smelt *(Spirinchus thaleichthys)*, the Delta Smelt *(Hypomesus transpacificus)*, Steelhead *(Onchorhychus mykiss)*, sturgeon *(Acipenser spp)*. and surfperch (Embiotocidae) (Herbold et al., 1992). The reasons for these declines are unclear, as there are numerous anthropogenic and natural factors that could potentially affect fish populations (e.g., see Foe, 1995; Moyle et. al, 1992; Laevastu, 1993). Water flow through the Delta is correlated with several population fluctuations, but the mechanisms that link such flow to healthy populations (e.g., better food production, greater contaminant dilution, etc.) and the role that other factors may play is not clear. In order for CALFED to restore fish populations in the system, a better understanding of the mechanisms causing these declines is needed.

Previous and ongoing monitoring bioassays have identified that acute toxicity to aquatic organisms occurs at certain times and places in the system (Ogle et al., 1996, 1998; Fox and Miller 1996), which in turn suggests that chronic toxicity, including both mortality and sublethal effects (e.g., reproductive effects) probably exists, and could be widespread. If widespread chronic toxicity to fish exists, as seems likely, then it is almost certain that such toxicity has contributed to the observed fish population declines, and if these fish populations are to be restored to their former abundance and health, then such chronic toxicity must be identified and remediated.

While monitoring for chronic toxicity through the use of toxicity testing (i.e., bioassays) will be an essential component of any evaluation of chronic tooxicity in the estuary, it must also be recognized that chronic contaminant effects on fish can be varied, depending on their accumulation and metabolism of contaminants, and the extent of exposure can be identified through careful application of sublethal indicators, such as biomarkers (e.g., Spies et al., 1996). The existing data on trace substances and contaminants in the Bay-Delta water sediment and fish tissues are insufficient to characterize the risk to fish resources, because: 1) the data are not comprehensive enough in space and time; 2) chemical measurements are insufficient in many instances to characterize risk, even direct measurements of chemicals in tissues (Iannnuzzie et al, 1995); 3) most chemical measurements include all the chemical forms, including those that are not biologically available and non-toxic; 4) many potential toxicants are not being measured in the existing monitoring programs; and 5) many areas of the estuary, particularly within the Delta, are not being monitored for either contaminants or toxicity by the existing monitoring programs. Biomarkers have been used extensively to evaluate the exposure and effects of multiple environmental contaminants, as they accurately integrate the accumulation of biologically active contaminants from all of the exposure pathways, usually cost less than contaminant analyses, and can serve as an "early-warning" system for more drastic effects of contaminant exposure (Teh et al., 1997). Biomarkers are most usefully applied within the context of more general studies of fish health and to rule in or rule out exposure and effects from contaminants for species of concern.

Acute and Chronic Toxicity Assessment

The effects of contaminants can be expressed in larvae, juvenile and adult fish in a variety of ways: behavioral modifications, atrophied tissues, histopathological alterations, reduced fecundity, slower growth, greater energy consumption, etc. However, the maintenance of populations requires high survival of individuals through healthy growth and reproduction, particularly from gametogenesis through juvenile stages. Therefore, to understand how contaminants may affect survival, growth and reproduction, biomarker analyses, both of exposure and effect, must be linked as well to these higher order physiological processes. The early stages are also the most sensitive life stages (Rosenthal and Alderdice 1976), indicating that the emphasis of any chronic fish toxicity studies should ultimately be on growth and reproduction. Survival through these stages reflects the ability of the aquatic ecosystem to maintain healthy populations. The adult stages are also subject to a variety of potentially lethal stresses (low oxygen, toxic blooms, fishing, predation, water diversions), but it is the quality of the environment for reproduction and survival through early life stages that is key to maintaining or restoring healthy fish populations. A healthy environment for fish has both good habitat and good water quality. Good water quality depends on having concentrations of contaminants that do not interfere with the general health, particularly growth and reproduction, especially through larval and juvenile stages.

For the past 20 years, diagnoses of problems in California aquatic environments have relied on gross chemical analyses of water, tissues and sediments and short-term acute toxicity testing. These are the necessary first steps in environmental protection, but they may not have been sufficient to diagnose the subtler effects of chronic toxicity played out over multiple generations of aquatic organisms

The Bay-Delta ecosystem receives a large variety of potential toxicants (Gunther et al., 1987; Davis et al., 1992), including significant quantities of pesticides and metals, from surrounding agricultural lands and suburban and urban landscapes, particularly in the Delta (e.g., Menconi and Cox, 1994). Moreover, the highest use of pesticides occurs in the late winter and spring, when most of the above species reproduce (Adams et al., 1996) and are most susceptible to contaminant impacts. Many of these contaminants can disrupt endocrine function, or otherwise adversely impact fish embryos, larvae and juveniles. A study of larval striped bass in the Sacramento River revealed chronic liver lipidosis, consistent with an effect of toxicants (Bennet et al., 1995). A study of starry flounder (*Platichthys flesus*) showed that contaminants and contaminant-induced enzymes are strongly linked to poor quality eggs, poor fertilization and poor larval development in the Central Bay starry flounder population (Spies and Rice, 1988). In addition, a recent study has pointed to alterations of sex steroid concentrations in carp that correlate with dissolved pesticides in US river waters, including a strong hint that effects may occur in the SF Bay-Delta (Goodbred et al., 1997). Contaminants can alter endocrine function in wild populations of fish (Rolland et. al, 1997; Harries et al., 1996; Spies et al., 1998), and such alterations may be expressed as poor egg quality, reduced fecundity, inhibition of spawning, and reduced survival of eggs through hatching. Some overall assessment of the potential for conditions in the system to affect growth and reproduction of fish is needed as a step towards rejecting the hypothesis that contaminants are important factors affecting populations of fish. Any reproductive effects are probably mediated through endocrine disruption and may be widespread, but there has been little follow up work that would indicate how pervasive such effects are in the Bay-Delta system, i.e. in other species.

Although the last several years have seen great advances in our understanding of the distribution and abundance of contaminants in the estuary (e.g., SFEI, 1995), there has not been as much emphasis on the risk they might pose to the health of individuals and populations in the ecosystem as a whole. Defining the average chemical contaminant field, as has occurred through implementation of the Regional Monitoring Program (RMP) by the San Francisco Estuary Institute, is a large step forward in understanding risk to the fauna and flora. In addition, a better understanding of transient pulses of contaminants, particularly pesticides, that occur in the upper Bay, Delta and rivers is being obtained. To complete the risk paradigm, we must determine the degree of contaminant exposure, if there is link between exposure and sublethal and chronic toxicity, and then use the exposure-effect relationships to determine the risks to fish populations in the catchment of the estuary.

A comprehensive contaminant risk assessment for fish, particularly for chronic growth and reproductive risks, in the Bay-Delta and its catchment is multi-dimensional. That is, there are many different chemicals that enter the system. These chemicals enter at multiple points and at certain times and undergo chemical change, absorption, and metabolism. They can enter the aquatic environment as chronic sources, or as pulses of contaminated water that moves downstream. The risks must be characterized to multiple species and the various life stages of each species that are also heterogeniously distributed in time and space. There are, therefore, chemical, biological, geographical and temporal complexities to the risk. Identifying the populations at risk and the times and places of greatest risk is challenging indeed, as we still have an incomplete picture of contaminants in the system.

Significance

The maintenance of healthy populations of fish is dependent on successful adjustment to constantly changing physical and biological conditions of the ecosystem. Contaminants may compromise the ability of fish and other aquatic organisms to survive other stresses in the system. Ultimately, fish that are unable to compensate for additional stress will show reductions in survival, growth and reproduction. Building on related efforts to better define the contaminant field in time and space, studies that identify contaminant effects (utilizing biomarkers relating exposure to growth, reproduction and, ultimately, survival) will help us identify and remediate situations where fish species are at risk.

Recommendations

1. Review and interpret existing information with respect to the probability of chronic toxicity to priority fish populations, particularly with respect to growth and reproductive impacts. Also, identify resident fish that are amenable to chronic toxicity testing in the laboratory and appropriate for field biomonitoring programs.

2. Improve the monitoring of ambient water chronic toxicity to fish through bioassays using resident fish species (use of species currently at risk is not recommended), and monitoring of key habitat areas not currently being monitored on a regular basis.

3. Develop assays for inhibition of growth and reproduction of fish using a convenient species (may not be a species at risk) in order that waters collected in a large number of places and at different times may be assessed for risk

4. Identify biomarker responses, including biomarkers of exposure, growth and reproductive health, in laboratory held-fish exposed to contaminated water..

5. Assess any chronic growth and reproductive impairment that may be occurring in priority fish populations. Biomarkers should be used to establish what links may exist between contaminant exposure and impaired growth and reproduction.

References

Adams, W., L. Davis, J. Gidings, L. Hall, Jr., R. Smith, K. Solomon and D. Vogel. 1996. An ecological risk assessment of diazinon in the Sacramento and San Joaquin River Basins. Prepared for Ciba-Geigy Corporation, Ciba Crop Protection, Greensboro, North Carolina.

Bennet, W., D.J. Ostrach, and D.E. Hinton. 1995. Larval striped bass condition in a drought-stricken estuary. Biol. Applications 5, 680-692.

Davis, J.A., A.J. Gunther and J.M. O'Connor. 1992. Priority pollutant loads from effluent discharges to the San Francisco Estuary. Water Environment Research. 64:134–140.

Foe, C. 1995. Evaluation of the potential impact of contaminants on aquatic resources in the Central Valley and Sacramento-San Joaquin Delta Estuary. June 1995. Central Valley Regional Water Quality Control Board. Sacramento, CA.

Fox P, Miller J (1996) Fathead minnow mortality in the Sacramento River. IEP Newsletter 9(3):26-28.

Goodbred, S.L., R.J. Gilliom, T.S. Gross, N.P. Denslow, W.L. Bryant and T.R. Schoeb. 1997. Reconnaissance of 17ß-estradiol, 11-ketotestosterone, vitellogenin, and gonad histopathology in common carp of the United States: potnetial for contaminant-induced endocrine disruption. U.S. Geol. Survey, Sacramento, CA. Open-File report 96-627, 47 pp.

Gunther, A. J., J.A. Davis and D.J.H. Phillips. 1987. An Assessment of The Loading of Toxic Contaminants to The San Francisco Bay–Delta. Prepared for The San Francisco Estuary Project, USEPA, and The State Water Resources Control Board of California by the San Francisco Estuary Institute, 330 pp.

Harries, J.E., D.A. Sheahan, S. Jobling, P. Mathiessen P. Neall, E.J. Routledge, R. Rycroft, J.P. Sumpter and T. Taylor. 1996. A survey of estrogenic activity in United Kingdom inland waters. Environ. Toxicol. Chem. 15: 1993-2002.

Herbold, B., A.D. Jassby and P.B. Moyle. 1992. Status and Trends Report on aquatic resources in the San Francisco Bay Estuary. San Francisco Project. PO Box 2050, Oakland, CA 94604-2050, 257 pp.

Iannuzzie, T.J., N.L. Bonnvie, SL. Huntley, R.J. Wenning, S.P. Truchon, J.D. Tull and P.J. Sheehan. Comments on the use of equilibrium partitioning to establish sediment quality criteria for nonionic chemicals. Environ. Toxicol. Chem.14, 1257-1259.

Laevastu, Taivo. 1993. Marine climate, weather and fisheries. Halstead Press, New York. 204 pp.

Menconi, M. and C. Cox. 1994. Hazard assessment of the insecticide diazinon to aquatic organisms in the Sacramento-San Joaquin river system. Administrative Report 94-2, California Department of Fish and Game, Rancho Cordova, CA.

Moyle, P.B., B. Herbold, D.E. Stevens and L.W. Miller, 1992. Life history and status of the Delta Smelt in the Sacramento-San Joaquin River estuary in California. Trans. Am. Fish. Soc. 121, 67-77.

Ogle, S., J. Costifas, C. Foe, V. Connor, L. Deanovik, T. Kimball and E. Reyes. 1996. A preliminary survey of sediment toxicity in California's Central Valley. PWT Report from Pacific Eco-risk Laboratories, Central Valley Regional Water Quality Control Board and University of California. Davis, 24 pp.

Ogle, S., A. Gunther, R. Hoenicke (1998) Episodic toxicity in the San Francisco Bay system. IEP Newsletter 11(2):14-17.

Rolland RM, Gilbertson M, Peterson RE, eds. "Chemically induced alterations in functional development and reproduction of fishes." SETAC Press, Pensacola FL. (1998).

Rosenthal, H. and D.F. Alderdice. 1976. Sublethal effects of environmental stressors, natural and poluional, on marine fish eggs and larvae. J. Fish. Res. Bd. Can. 33, 2047-2065.

San Francisco Estuary Institute. 1995. San Francisco Estuary Regional Monitoring Program for Trace Substances, 1994 Annual Report. San Francisco Estuary Institute, Richmond, CA. 339 pp.

Spies, R.B. and D.W. Rice, Jr. 1988. Effects of organic contaminants on reproduction of the starry flounder *Platichthys stellatus* in San Francisco Bay. II. Reproductive success of fish captured in San Francisco Bay and spawned in the laboratory. Mar. Biol. 98, 191-200.

Spies, R.B., J.J. Stegeman, D.E. Hinton, B. Woodin, R. Smolowitz, M. Okihiro and D. Shea. 1996. Biomarkers of hydrocarbon exposure and sublethal effects in embiotocid fishes from a natural petroleum seep in the Santa Barbara Channel. Aquat. Toxicol. 34, 195-219.

Spies, R.B. and P, Thomas. Reproductive and endocrine status of mature female kelp bass *Paralabrax clathratus* from a contaminanted site in the Southern California Bight and estrogen receptor binding of DDTs, Chapter 9, in Rolland R.M., Gilbertson, M., Peterson R.E.,(eds.) Chemically induced alterations in functional development and reproduction of fishes. SETAC Press, Pensacola FL. (1998).

Teh, S., S.J. Adams, and D.E. Hinton. 1997. Histopathological biomarkers of anthrropogneic stress in resident redbreast sunfish (Lepomis auritus) and largemouth bass (*Micropterus salmoides Lacepede*) from contaminant impacted sites Aquatic Toxicol. 37, 51-70.